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TITLE OF INVENTION (280 characters max)

ORIENTED POLYMER FIBERS WITH FUNCTIONAL GRADIENTS BY ELECTROPULLING

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ENCLOSED APPLICATION PARTS (*check all that apply*)

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Respectfully submitted,

SIGNATURE Lisa A. Haile DATE March 31, 2004

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on

ORIENTED POLYMER FIBERS WITH FUNCTIONAL GRADIENTS BY ELECTROPULLING

by

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Docket No.: UCLA1540

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Oriented Polymer Fibers with Functional Gradients by ElectroPulling

1. Background

Electrospinning, or electrostatic fiber formation, is a method of producing fibers with diameters ranging from 10 nm to 10 μm by accelerating a jet of charged polymer solution within an electric field[1]. Electrospinning is a rapid, simple, and inexpensive method to fabricate high aspect ratio, submicron diameter size fibers with high surface area. Potential applications of such fibers include filtration[2] and composite materials[3], catalyst support[4], optical[5] and chemical[6] sensors, and drug delivery[7], etc. Electrospun conducting polymers have been used to fabricate metallic nano-tubes[8], nano-wires[9] and field-effect transistors[10]. Electrospun non-woven biodegradable fabrics have been reported for adhesion barrier[11], wound dressing[12] and tissue engineering[13] with controlled surface chemistry[14] and protein contents.[15, 16]

Currently, fiber mat, or fiber wood, fabricated by electrospinning has been studied by many research groups. Typically, during electrospinning, a reservoir of polymer fluid is connected with a large electric potential and fluid is delivered to the tip of a small capillary. The electrical charge that develops at the fluid's free surface interacts with the external electric field, resulting in the emission of a steady fluid jet that thins as it accelerates towards the collector. In most cases, the jet experiences a whipping instability, leading to bending and stretching of the jet, observed as loops of increasing size as the instability grows. The whipping jet thins dramatically, by as much as 3 orders of magnitude, while traveling the short distance between the electrodes. The presence of polymer in solution leads to the formation of fine solid fibers as the solvent evaporates. The final formation of the fiber mat can be directly influenced, but not limited, by several factors such as: the driving electrical field, activity of the polymer within the solvent, the viscosity of polymer solution, the evaporation rate of the solvent, and the surface charge of the polymer jet/fiber. In almost all reports, the final fiber mat that forms on the collector presents random fiber orientation. The looping and spiraling path of fibers, due to bending, whipping, and other instabilities that occur during fiber formation. Quasi "oriented fiber mat" has been reported by collecting the electrospun fiber by a "rotating and translating ground target", but the reported fiber mat presents poor 2-dimension preferentially orientation. Fiber alignment has been produced with a sharp-edged rotating disk[13], and by collecting fibers between two conductive electrodes[17], but neither technique produces three dimensionally aligned fibers. For biomedical applications such as, but not limited to, the regeneration of neural tissues, cardiac tissues, and smooth muscle layers of many organs, oriented bioactive fibers offer the potential of promoting cell attachment, alignment, differentiation, and function.

2. Description of the invention

ElectroPulling produces surface functionalized polymer fibers with controlled three dimensional orientations. Unlike the state of the art electrospinning, which involves whipping instability, electropulling creates quasi linear jet motion. This is accomplished by subjecting a metastable liquid dispersion to a high voltage electrical field to create liquid column motion, phase separation and segregation within the liquid column, and fiber formation during solvent evaporation. The metastable dispersion of multiple liquid phases can include additives to control solubility, charge, viscosity, surface tension, evaporation, boiling point, refractive index, to influence the final chemical, physical, and biological properties of the resultant fibers.

Our electropulling set up is shown in Figures 1. The setup is different from all known electrospinning facilities. The key point of our electropulling setup is a special electrode, which located under the jet and distances the grounded collector by 6 inches to one feet. This special electrode has a floating potential and also has a function as "second collector". The polymer solution jet was electropulled from the floating electrode toward the collector. Finally, 3-dimensional oriented fiber is formed between the grounded collector and the floating electrode. In principle, any polymer which can be dissolved in a solvent can be electrospun to form 3-dimensional oriented fiber.

2-1. Liquid phase separation in polymer solution

The invention approach 1 employs a method of liquid phase separation.

Example 1: PVDF-TrFE (65/35 wt% Polyvinylidene fluoride-co-trifluoroethylene) fiber.

Polyvinylidene fluoride (PVDF) molecule has polarity and hence this material possesses piezoelectricity, pyroelctricity, and ferroelectricity. PVDF, especially, co-polymer PVDF-TrFE (trifluoroethylene) (65/35 wt%), in film and bulk has been used widely. If this polymer can be form in fiber, its application will be extended very much.

Based on the method of liquid phase separation, 2 g of PVDF-TrFE (65/35 wt%) copolymer pellets was dissolved in 15 g of methyl ethyl ketone by stirring at room temperature for 24 hours, until a clear solution was obtained. This polymer solution is mixed with DI water to produce 33 wt% water to solution ratio (i. e., H_2O: Polymer solution = 1:2 weight ratio) by ultrasonication for 4 min (alternating 2 sec pulse / 2 sec stop). The mixture was electropulled under an applied voltage of 27 kV dc and 3-dimensional oriented PVDF-TrFE fiber was formed between the floating electrode and the grounded corrector (the length is about 6 inchs, i. e., 15 cm).

Figure 2 shows the SEM images of PVDF-TrFE (65/35 wt%) copolymer fiber electropulled from polymer solution mixing with water. The length of the fiber is 15 cm (equals to the distance from the 2nd collector to the 1st collector screen). Liquid phase separation results in smooth, oriented, electropulled fibers (see in Fig 2).

2-2. Fabrication of fibers with 3-dimensional orientation by doping ions

Based on the approach 1 of liquid phase separation, the invention approach 2 is to increase charge density on the surface of polymeric fibers by doping cations/anions to produce 3-dimenssion oriented fiber mats using polymers with little or no polarity. The charge density can be increased by the use of multi-valent cations/anions, or by altering the ionic concentration.

Example 2: Solution of PLGA/chloroform mixed with NaCl water solution.

The mixed liquid is prepared as follows. 1.8 g of PLGA and 12 g of chloroform were shaken for 24 h. Then a non-solvent was prepared by dissolving 1.0 g NaCl in 10 g of DI-water. The entire 13.8 g of PLGA/chloroform solution was mixed with 4 g of the NaCl water solution by ultrasonication of 2 sec pulse and 2 sec stop for 4 min. The resultant mixture is electropulled under an applied voltage of 30 kV dc, and the pulling distance of 15 cm between 2nd collector and 1st collector screen. Figure 3(a) shows the aspect of the fiber mat (length is 15 cm) with 3-dimensional orientation and Fig. 3(b) shows a SEM picture of this fiber mat.

Example 3: Incorporation of bioactive molecules (laminin) and NaCl water solution in PLGA/ chloroform

1 g of laminin water solution (concentration is 100 μg of laminin in 1 cm^3 water) and 3 g of the NaCl water solution (1.0 g NaCl in 10 g of DI-water) were added in to 1.8 g of PLGA in 12 g chloroform. These liquids were mixed at 0 °C (ice-water bath) by ultrasonication of 2 sec pulse and 2 sec stop for 4 min. The resultant mixture is electropulled under an applied voltage of 30 kV dc, and separation distance of 15 cm between the 2nd collector and the 1st collector. The fiber mat with 3-dimensional orientation was obtained. Figure 4(a) shows the aspect of the fiber mat (length is 15 cm) with 3-dimenssion orientation and Figure 4(b) shows a SEM picture of this fiber mat. During phase separation, the water layer is assumed to form on the outer surface of the jet column. Since laminin and many other bioactives have higher solubility in water than chloroform, these bioactives are likely to concentrate on the outer surfaces of the fibers. For applications where it is desirable to incorporate bioactives within the bulk of each fiber, surfactants can be added to increase the solubility of the bioactive molecules within the polymer liquid phase. These principles apply for incorporating molecules with low water solubility such as hydrophobic drugs, steroids, etc., into the fibers.

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Figure caption:

Fig. 1 Schematic of electropulling set up

Fig. 2 SEM pictures of Example 1.

Fig. 3 (a) Aspect of the fiber mat (length is 15 cm) with 3-dimenssion orientation;
(b) SEM picture of Example 2.

Fig. 4 (a) Aspect of the fiber mat (length is 15 cm) with 3-dimenssion orientation;
(b) SEM picture of Example 3.

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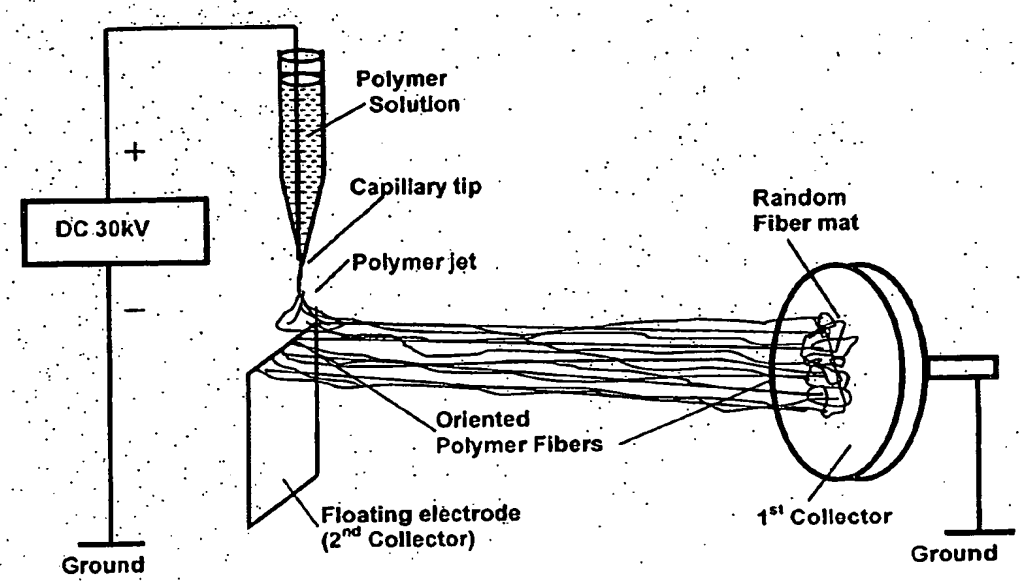

Fig. 1 Schematic drawing of the setup for electro-pulling 3-D oriented polymer fibers.

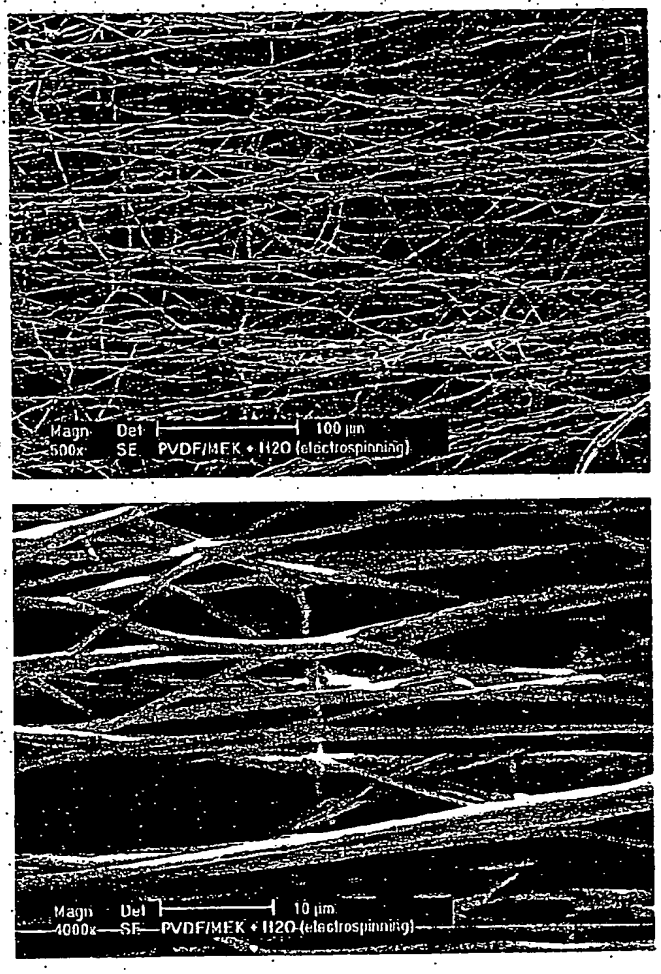

Fig. 2 SEM pictures of PVDF-TrFE fiber fabricated by ElectroPulling (Example 1).

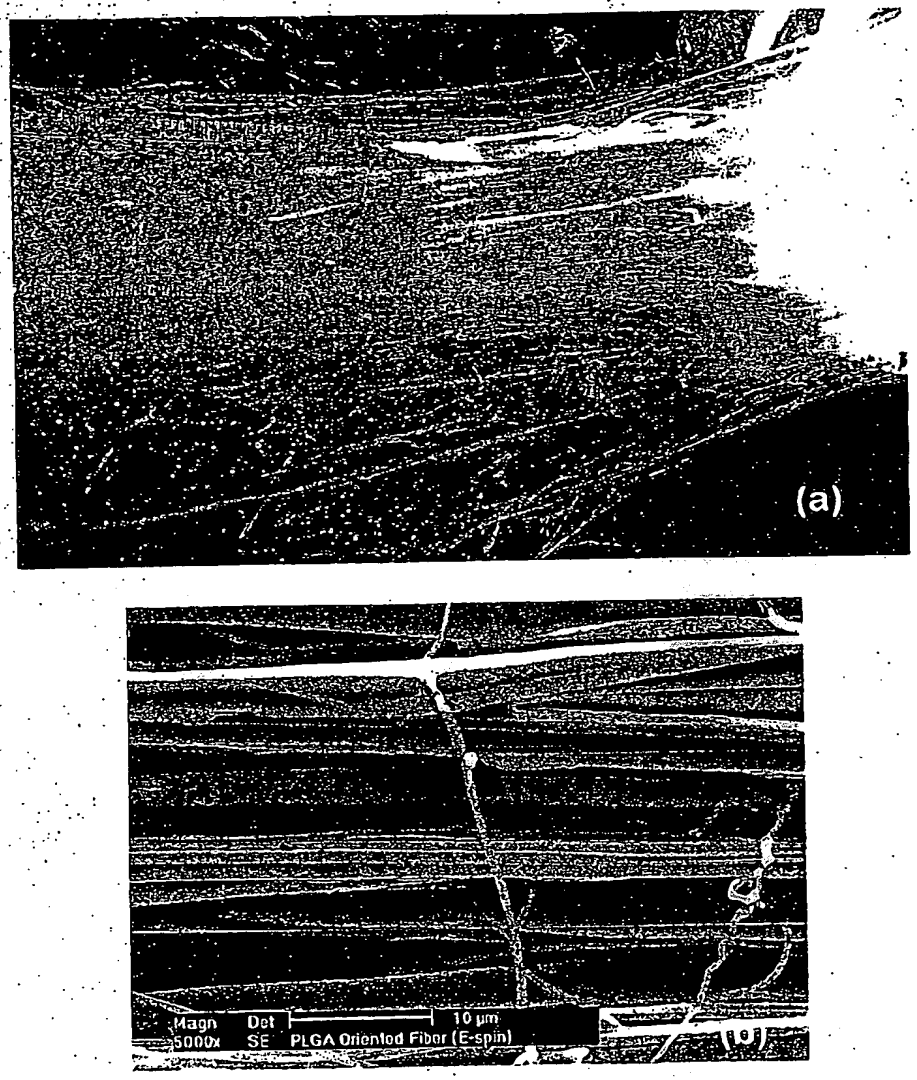

Fig. 3 (a) Aspect of the ElectroPulled fiber (length is 15 cm) from PLGA+NaCl water solution with 3-dimenssion orientation; (b) SEM picture of the fiber (Example 2).

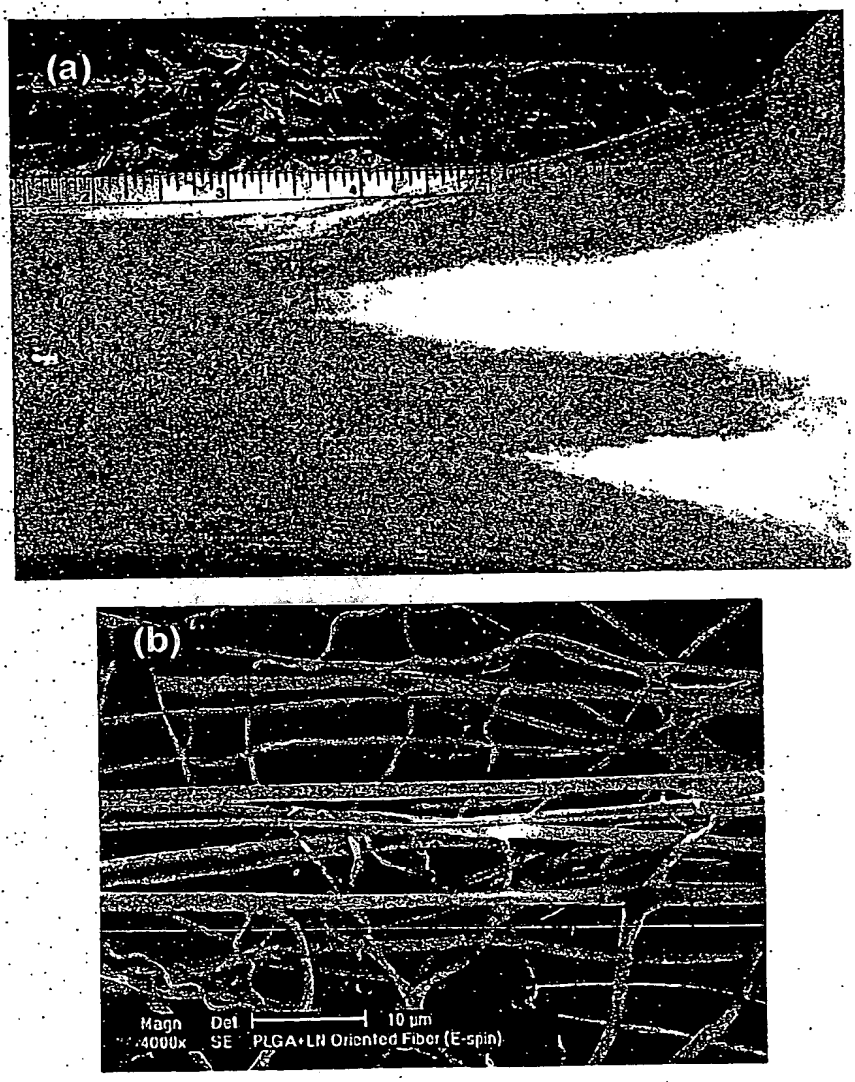

Fig. 4 (a) Aspect of the fiber mat (length is 15 cm) with 3-dimenssion orientation; (b) SEM picture of Example 3.